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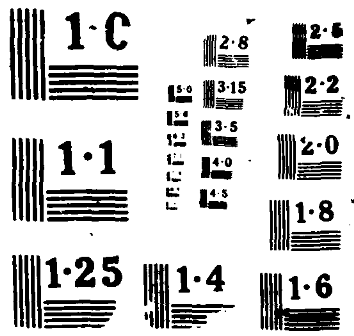
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ELECTRICAL/PNEUDRAULIC

DESIGN CONSIDERATIONS

THESIS

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Captain, USAF

AFIT/GLM/LS/87S-25

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ELECTRICAL/PNEUDRAULIC DESIGN CONSIDERATIONS

THESIS

Presented to the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

Ricky L. Fennell, M.A.

Captain, USAF

September 1987

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Preface

The purpose of this research was to examine ways that the reliability and maintainability of electrical and pneudraulic components and systems could be improved. Problems encountered with the components and systems were revealed as well as recommended corrective actions. Though several data sources were tapped this research does not provide the only ways reliability and maintainability could be improved. Interviews with maintenance technicians, component design analyses, and "hands-on" maintenance experience can provide additional suggestions.

In preparing this thesis I have received a great deal of help from others. I want to thank my thesis advisor, Mr. Jerome Peppers, for his patience and understanding in seeing me through this sometimes trying experience. Thanks is also due to the electrical and pneudraulic technicians at the 906th Tactical Fighter Group and the 4950th Test Wing for allowing me to tap their vast maintenance experience and wisdom. And last but not least, I thank God for blessing me with a loving and faithful family. Without my wife and children supporting me, surely AFIT would be a long and arduous event.

Ricky L. Fennell

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Abstract

The purpose of this research was to examine ways that the reliability and maintainability (R&M) of aircraft electrical and pneudraulic components and systems could be improved. To accomplish this task two R&M databanks for the components under review were researched. Added to this information were the opinions of electrical and pneudraulic aircraft maintenance technicians from two organizations assigned to Wright-Patterson AFB OH.

The results of the document reviews and interviews were a list of specific problem areas and suggested corrective actions for each. These problem areas were then categorized into general recommendations to improve the reliability, maintainability, and a subset of maintainability, accessability, of the electrical and pneudraulic systems.

This thesis should be looked at as a management document providing general guidelines for designing aircraft electrical and pneudraulic systems. As these systems are functionally similar to other aircraft systems, such as fuel, propulsion, and environmental systems, the recommendations put forth may also apply to those systems.

ELECTRICAL/PNEUDRAULIC DESIGN CONSIDERATIONS

I. INTRODUCTION

Background

Rarely do the Air Force's budget requests and its actual funding levels match. Sometimes the Air Force receives more than it requests but more often it receives less. In the years when the budget requests have exceeded the funding levels this deficit would obviously have to be made up somehow. Some element(s) of the budget would have to absorb the reductions. But even in the "feast" years where the funding levels have matched or exceeded the budget requests, it can not be assumed that all of the appropriations will be 100% funded. Consider what happened from 1976 to 1982. The Air Force funding levels ranged from a low of 94.0% to a high of 114.4% (Table I) while the spares funding level during that same period never exceeded 60% (Table II). Without adequate funding, the required spares could not be bought. Without the appropriate amount of spares, the Air Force's supportability would decrease which would in turn decrease the combat capability of the Air Force. Major Gordon Hodgson noted in a 1984 Air Force Journal of Logistics article, "Reliability and Maintainability in the Air Force", that:

Table I

AIR FORCE REQUIREMENTS AND FUNDING

(In billions of dollars)

Fiscal Year	Budget Request	Funded	Percent
1976	30.2	28.4	94.0
1977	32.1	31.1	96.9
1978	34.7	32.9	94.8
1979	34.9	34.9	100.0
1980	38.4	41.6	108.3
1981	45.7	52.3	114.4
1982	67.0	64.9	96.9

(12) for the budget request
(2:C-18) for funding level

Table II

SPARES REQUIREMENTS AND FUNDING

(In billions of dollars)

Fiscal Year	Budget Request	Funded	Percent
1976	1.5	0.6	40.0
1977	1.5	0.8	53.3
1978	1.8	0.8	44.4
1979	2.4	1.0	41.7
1980	3.6	0.9	25.0
1981	4.4	2.3	52.3
1982	5.7	3.4	59.6

(10:10)

> In response to this dilemma, the Assistant Secretary of the Air Force for Research, Development and Logistics, in a memorandum to the Air Force Vice Chief of Staff, suggested that technology could provide increased supportability and lower overall support costs through more extensive application of reliability and maintainability (R&M) improvements (10:10).

General James Mullins, former Commander, Air Force Logistics Command, gave an address at the Martin Marietta, Denver aerospace facility in 1984 entitled "Reliability: Key to Cost Reduction." In the address, General Mullins cited the savings that could be realized with improved reliability.

> ...there would be substantial savings in operations and maintenance costs, about $7.5 billion this year, and almost $9.5 billions in fiscal 1985. These savings, when coupled with additional savings in civilian logistics personnel, could easily free 20 percent of the entire Air Force budget to be used in more productive and meaningful ways (13:16).

A large part of the savings would be accomplished in the reduction of aircraft spares required. The very area in which the Assistant Secretary of the Air Force for Research, Development and Logistics suggested that R&M could increase supportability and lower overall costs. General Mullins supported this thought when he said that,

> For a 25 percent improvement in MTBF (mean time between failure), perhaps from 500 hours to 625 hours, you could reduce the spares requirement almost 40 percent and still maintain the same aircraft availability. If you could double the present MTBF, you would eliminate almost 80 percent of the present spares requirement (13:16).

Major Hodgson pointed out the potential return on investment that could be accomplished through R&M. He cited a 1974 Logistics Management Institute study that "developed an optimization technique to determine the system reliability that would result in lowest life cycle costs." This study, based on historical data for four weapon systems, showed the potential savings had system reliability been optimized early in system development. "While additional funds would have been required to accomplish this development, substantial returns were indicated and a significant improvement in the probability of predicted mission success occurred." The findings of the study (Table III) point out the great potential for return on investment in R&M (10:12).

Table III

POTENTIAL RETURN ON R&M INVESTMENT

System	Additional Investment in R&M ($ millions)	Net Life Cycle Cost Savings ($ millions)	Percent Return on Investment over 10 years
F-4C	$ 134	$ 453	338
F-105D	194	580	299
B-52H	76	185	240
C-141A	271	1608	593

Avg Percent Improvement in Prob of Mission Success: 54%

Avg Life Cycle Cost Savings: 27%

Avg R&M Investment as Percent of Present Life Cycle Cost: 8%

(10:12)

In a March 1985 memorandum to all major commands and separate operating agencies, then Air Force Chief of Staff General Charles Gabriel and then Secretary of the Air Force Verne Orr emphasized the importance of reliability and maintainability of Air Force weapon systems. In their memorandum, they stated,

> For too long, the reliability and maintainability of our weapon systems have been secondary considerations in the acquisition process. It is time to change this practice and make reliability and maintainability primary considerations. Reliable weapon systems reduce life cycle costs, require fewer spares and less manpower, and result in higher sortie rates. Similarly, maintainable weapons require fewer people and lower skill levels, and reduce maintenance times. Equally important, good reliability and maintainability improve the mobility of our forces-fewer people and less support equipment to deploy. They reduce dependence on airlift and prepositioning, while increasing our ability to generate sorties (9:11).

Willis Willoughby expressed similar concern to that of General Gabriel and Secretary Orr in an article six years earlier titled "Reliability by Design, Not by Chance".

> ...performance has seldom been a limiting factor; indeed, performance has usually exceeded requirements. At the same time, however, reliability requirements, which in some instances were questionably low to begin with, are being missed by wide margins; yet many of these products will be in service for ten to twenty years or more. A high-performance product has little value, even as a deterrent, if it cannot consistently deliver this performance because it is either broken down or breaks down immediately upon being pressed into service (17:341).

General Bryce Poe, who was then Commander, Air Force Logistics Command, in 1979 felt that not only were reliability and maintainability important but that they needed to be designed into weapon systems. He believed the Air Force should be proactive and not reactive when it comes to R&M. In his article "Getting Weapons That Do The Job", General Poe said,

> Availability of equipment has to do mainly with that equipment's reliability and maintainability. Lack of either greatly increases cost. So, that's really what we're talking about when we say life cycle costs. The cost of designing in reliability, versus the cost of making it work if we don't. In the words of the commercial, "pay me now or pay me later", the presumption is that it is a great deal cheaper to design in reliability than to make it work later if we don't (15:64).

A good example of the effectiveness of designing in reliability and maintainability is in the comparison of the F-4 and the F-15. By designing-in reliability, the F-15 has 20% higher reliability than the F-4 and it requires fewer skilled avionics technicians per squadron for maintenance (218 versus 307). Even more dramatic results are obtained when the F-4 and the Navy's F-18 are compared. The F-18's radar has 8,000 fewer parts than the F-4 radar and its engine has 7,700 fewer parts. The F-18 uses two hydraulic pumps instead of four, has improved avionic cooling, and uses ground cooling fans. The F-18 has experienced an average 2.8-3.5 flight hours between failure (the F-4 averages less than one hour), a savings of 50% in required maintenance man-hours per flight hour, and greater than a 20% overall reduction in operating and support costs (8:29).

Improving the reliability and maintainability of aircraft and their imbedded systems and components has wide-ranging, positive impacts. The need for spares, support equipment, and manpower decrease which drives down the life cycle cost of aircraft. What increases is the Air Force's availability of aircraft, number of sorties generated, mobility, sustainability, and combat capability. Improved reliability and maintainability in design will assure the Air Force will be able to avoid maintainability fiascos such as the F-4 ejection seat. Actually nothing is wrong with the ejection seat itself, but it has to be removed from the aircraft to reach a particular radio every time that radio fails. This problem reportedly cost the Air Force one-quarter million dollars a month (over 58,000 manhours) in logistics support (15:60); an expenditure which could have been avoided had R&M been taken into consideration in the F-4 design.

Problem Statement

Billions of dollars have been spent every year in the acquisition of aircraft weapon systems. Once the aircraft were fielded, billions more were spent in their logistical support. One can project enormous potential savings through improved reliability and maintainability. Modern U.S. military aircraft are incredibly complex and designed to perform a broad spectrum of missions and, therefore, they incorporate a variety of systems. This research was designed to focus on two systems common to all aircraft (electrical and pneudraulic systems) and to illustrate how reliability and maintainability might be improved. The improvements could affect the entire Air Force aircraft inventory because many could be retrofitted.

Research Objectives

This paper had two objectives. 1) How could the reliability of electrical and pneudraulic systems and their components be increased? 2) How could the maintainability of electrical and pneudraulic systems and their components be improved? This paper presents suggestions/considerations to improve the design of the electrical and pneudraulic systems and their related components so that reliability will be increased and maintainability will be improved. This is a management document and not an engineering proposal. It proposes recommendations/ideas on how the components/systems should be designed, not how to build them.

An added benefit from this effort could be the cross-utilization of information. Other aircraft systems such as fuel, propulsion, and environmental systems have components functionally similar to the components found in electrical and pneudraulic systems. Proposed recommendations for change to the electrical/pneudraulic components may also apply to these other systems.

Scope

This research was restricted to the investigation of R&M improvements in electrical and pneudraulic systems and their respective components. These two systems were chosen because 1) conceptually they are similar in that they deal with a flow of energy--current in electrical systems and fluid in pneudraulic systems and 2) the components found in electrical and pneudraulic systems are functionally similar to components found in other aircraft systems such as fuel, propulsion, and environmental systems. The R&M improvements proposed for the electrical and pneudraulic components may therefore also apply to the other aircraft systems. The electrical and pneudraulic components listed in Table IV were investigated for R&M improvements.

This list was a grouping of all the components found within the systems, i.e., there are different types of valves in pneudraulic systems but for the purpose of this paper, they will be looked at together. Any R&M improvements for one type of valve will apply to other types unless otherwise specified.

A definition of the electrical and pneudraulic components may be found in Appendix C and D respectively.

Limitations

There were three limitations to this research.

1. Redundancy of systems was not addressed as redundancy increases the reliability of systems solely by

Table IV

COMPONENTS UNDER INVESTIGATION

Electrical Components

(in alphabetical order)

Circuit Protection Devices	Relays
Constant Speed Drives	Transformer-Rectifiers
Control Devices	Variable Resistors
Frequency and Load Controllers	Vibrators
Generators	Voltage Regulators
Hardware	Wiring
Motors	

Pneudraulic Components

(in alphabetical order)

Accumulators	Pressure Switches
Actuators	Pumps
Filters	Reservoirs
Fittings	Seals
Fuses	Tubing
Hardware	Valves
Pressure Regulators	

adding backup components. It does not improve the reliability of the individual components.

2. Electronic equipment was not covered. Electronic equipment is defined as being those devices which utilize electron tubes and semiconductors, have integrated circuits, and encompass equipment employed in the field of detection and tracking, recognition and identification, communication, aids to navigation, weapons control, countermeasures, and associated test equipment (16:249).

3. Time did not allow all possible sources of information to be tapped so the search for reliability and maintainability recommendations was confined to tenant organizations of Wright-Patterson Air Force Base OH.

Definitions

For the purpose of this study, the following terms are defined:

Reliability-the probability that an item will perform its intended function for a specified interval under stated conditions (16:576).

Maintainability-a characteristic of design and installation expressed as the probability that an item will be restored to a specified condition within a given period of time when the maintenance is performed using prescribed procedures and resources (16:406). Maintainability is concerned with ease and economy in the performance of maintenance. As such, an objective is to obtain the proper balance between elapsed time, labor time, and personnel skills at a minimum maintenance cost (1:44).

Accessability-a measure of the relative ease of admission to the various areas of an item (16:3). Accessability is considered a characteristic of maintainability in that maintenance has to be performed within a given period of time.

Component-an integral constituent of a complete (end) item. A component may consist of a part, assembly, or subassembly (16:144).

Electrical Equipment-apparatus, appliances, devices, wiring, fixtures, fittings, and material used as a part of or in conjunction with an electrical installation (16:248).

Pneudraulic Equipment-apparatus, appliances, devices, tubing, fixtures, fittings, and material used as a part of or in conjunction with a pneudraulic installation.

II. METHODOLOGY

Approach Overview

Three sources of information were used to determine how the reliability and maintainability (R&M) of electrical and pneudraulic systems can be improved.

1. A review of existing literature on R&M improvements for the components comprising the electrical and pneudraulic systems as well as for components functionally similar but found in other aircraft systems.

2. Discussions and interviews with electrical and pneudraulic aircraft maintenance technicians from the 4950th Test Wing and the 906th Tactical Fighter Group located at Wright-Patterson Air Force Base OH.

3. Discussions and interviews with the Advanced Tactical Fighter (ATF) engineers at the Aeronautical Systems Division, Wright-Patterson Air Force Base OH.

This approach is explained in the following sections. It is pictorially displayed in Fig. 1.

Document Review

The document review portion of the research effort entailed a review of the technical description of each component being investigated (see Chap I, Scope). This technical description came from two sources.

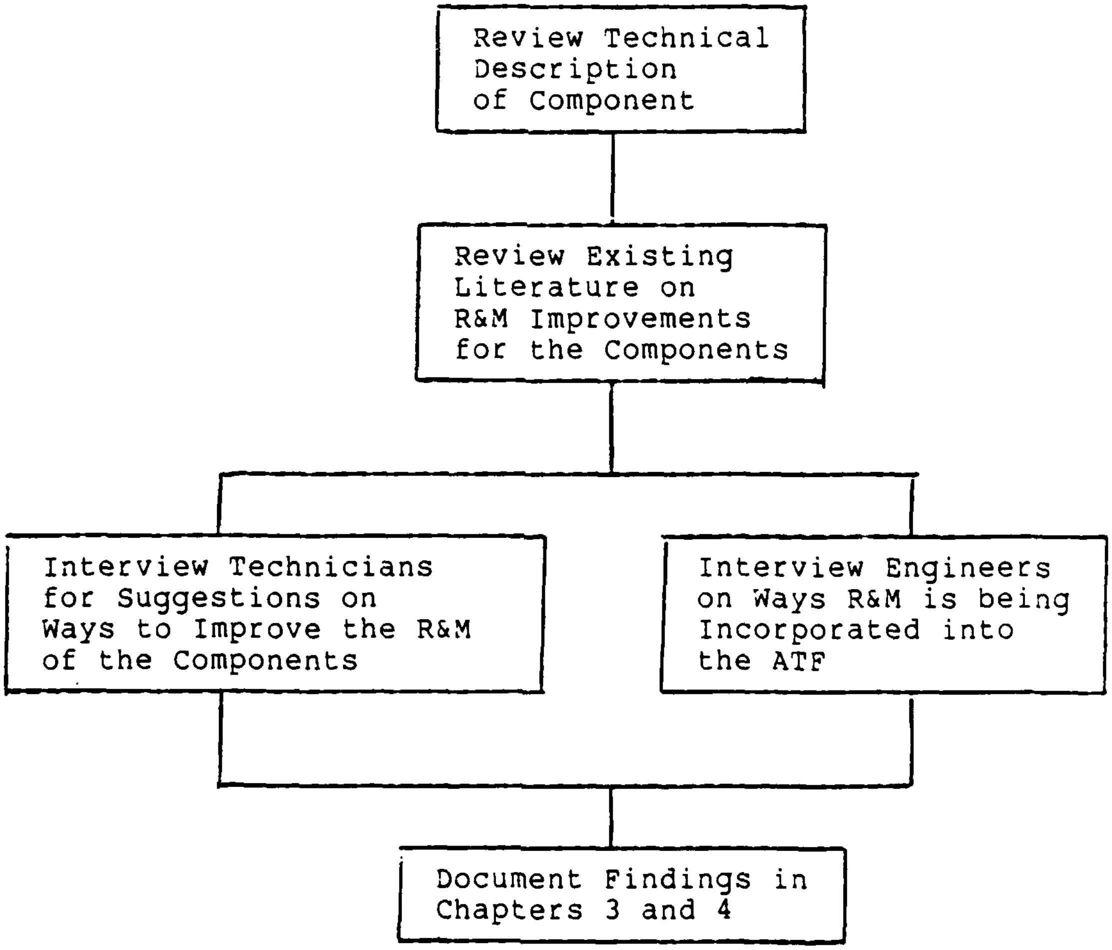

Fig 1. Methodology Approach

1. Aircraft Electrical System Career Development Course material, course 42350 vol 1-3 and course 42370 vo 2, published by the 3370th Technical Training Group, Chanute Air Force Base Il.

2. Aircraft Pneudraulic Repairman Career Development Course material, course 42152 vol 1-3, published by the 3370th Technical Training Group, Chanute Air Force Base Il.

Both of these Career Development Courses were studied thoroughly and carefully as though the researcher was attempting to qualify for an appropriate Air Force Specialty Code. This action, while very time-consuming, was essential to the detailed understanding of the two systems for this thesis effort. On completion, the researcher felt comfortable with his technical knowledge and understanding of the systems, components, and all parts required for effective operation. This acquired competence and understanding was invaluable in the later discussion and interviews with engineers and technicians. Further, it provided a sound base upon which to arrange their recommended actions.

Once the component technical descriptions were obtained, existing literature on R&M improvements for the components were reviewed. This review was expanded to components found in other aircraft systems that are functionally similar to the electrical and pneudraulic components. The literature originated from two sources.

1. Air Force Lessons Learned abstracts supplied by the Air Force Lessons Learned office (AFALC/LSL) at Wright-Patterson Air Force Base OH.

2. Air Force Logistics Research and Studies Program proposals supplied by the Air Force Coordinating Office for Logistics Research (AFALC/AFCOLR/XR) at Wright-Patterson Air Force Base OH.

Interviews

After the literature review was complete, two sets of interviews/discussions were conducted. The discussions were held with two groups of individuals. These groups were 1) electrical and pneudraulic aircraft maintenance technicians from the 4950th Test Wing (4950TW) and the 906th Tactical Fighter Group (906TFG) and 2) engineers working on the Advanced Tactical Fighter program at the Aeronautical Systems Division. Both groups are located at Wright-Patterson Air Force Base OH.

In the first set, maintenance technicians were interviewed. One to three technicians were interviewed as a group. The technicians chosen for the interview were at the discretion of the shop chief. As a guide, the shop chief was asked to pick individuals based on their maintenance experience and their ability to envision ways to improve the R&M of the systems they maintain. The shop chief was also aided by a list of questions (Appendix A) that could have been asked in the interview. All of these questions were not asked in each interview. These questions served as a guide for the researcher as he conducted an informal, brainstorming session with the participants. This took place four different times: once with the 4950TW electricians; once with the 906TFG electricians; once with the 4950TW pneudraulic technicians; and once with the 906TFG pneudraulic technicians.

In each session the researcher explained the purpose of the study, explained his understanding of the components comprising the systems, and then solicited comments and suggestions from the group via the interview questions. The interview questions were validated by six individuals (see Appendix B); three professors at the Air Force Institute of Technology, two maintenance shop chiefs from the 4950th Test Wing and a program manager (former Integrated Logistics Support Manager) from the B-1B Program Office. Table V contains a cross-reference of the interview questions and the research objectives they answer.

The second set of discussions took place with engineers working on the Advanced Tactical Fighter (ATF) at the Aeronautical System Division (ASD). This organization was selected because the ATF is in the Demonstration/Validation acquisition phase and the design is still evolving. The engineers were asked how R&M was being incorporated in aircraft today.

Results

The final product of the literature review and interviews and discussions were Chapters 3 and 4 and Appendix E and

Table V

QUESTION CROSS-REFERENCE

Objective: To propose ways to improve the reliability and maintainability of electrical and pneudraulic components.

Research Question No. 1 : How can the reliability of electrical and pneudraulic systems and their components be increased?

Research Question No. 2 : How can the maintainability of electrical and pneudraulic systems and their components be improved?

Question No.	Res. Ques. 1	Res. Ques. 2
1		X
2		X
3		X
4		X
5		X
6		X
7		X
8		X
9		X
10		X
11		X
12		X
13	X	
14	X	
15	X	
16	X	
17	X	
18	X	
19	X	

F of this paper. The chapters are broken out by the main categories into which the suggestions could be grouped. Each category contains a summary of the suggestions proposed. Appendix E and F contain the actual suggestions. These appendices are broken out by system (electrical and pneudraulic) and then sub-divided into their respective components.

Method Justification

The reason for choosing a literature review and interview method for this research stems from two facts: 1) while there is some information available, as was described in the document review section of this chapter, there is no all-inclusive data package to analyze; and 2) the designers and maintainers of weapon systems have a wealth of knowledge that would suit the objective of this research.

As the researcher was seeking to propose R&M improvements, it was necessary to seek primary sources with background in the electrical and pneudraulic field for suggestions. A problem with allowing the shop chief to select the personnel to be interviewed is that bias may have entered into the selection process. The shop chief may have selected individuals based on how well he (the chief) gets along with the individuals and not necessarily on the individuals' capability to provide quality inputs. In a pre-interview session with the shop chiefs, the researcher stressed the importance of carefully selecting individuals based on their maintenance experience and their ability to envision ways to improve the R&M of the systems they maintain. Bias was not considered as element of the resultant interviews and discussions.

III. ELECTRICAL SYSTEMS

Aircraft electrical systems are comprised of a number of components (see Table IV, pg 10) that generate, distribute, and use electrical energy. Some components use the electrical energy in its original form while others transform the electrical energy to mechanical energy by interfacing with other aircraft systems. Either way, problems have been noted with electrical components which affect the reliability and maintainability of the components and thus the electrical system. Some of these problems are inherent (designed into) to the electrical component. Some are induced (introduced) by the interaction of the electrical component with other aircraft systems or the environment in which the electrical component is operating.

This thesis is a managerial document which reviews problems, both inherent and induced, encountered with electrical components which affect the reliability and maintainability of the components. It also proposes corrective actions to the problems. A compilation of problems was obtained from four sources. The four sources are 1) the Air Force Lessons Learned data bank, 2) the Air Force Coordinating Office of Logistics Research data bank, 3) interviews with electrical technicians from the 906th Tactical Fighter Group, and 4) interviews with electrical technicians from the 4950th Test Wing. All four sources reside on Wright-Patterson Air Force Base, OH.

The results of the literature review and the interviews are contained in Appendix E, Electrical Components. Appendix E presents problems experienced with the electrical components and potential corrective actions for each problem. The problems, 103 in all, may be collected in three broad categories: Reliability, Maintainability, and a subset of maintainability, Accessability. The following paragraphs summarize the component categories. For further information, see Appendix E.

Reliability

The reliability of electrical components and electrical systems can be improved three ways:

1) Components should be kept electrically and physically separated as much as possible. If the separate entities of each component are retained, the failure of one component will not affect the function and reliability of a second.

2) Components should be designed to match their operating environment. If a component, by its mounted location, is going to be subjected to a harsh environment (such as in a wheel well), the component must be durable enough to withstand that environment. If the component durability does not match the environment, reliability will be compromised and maintenance costs increased.

3) A thorough system analysis of each system and the embedded components should be conducted during design to identify as many potential failure modes as possible.

Anticipation of the various failure modes will permit design and system engineers to design reliability in to the components, parts, and system.

Examples of each of these follows.

The first way to improve reliability is by keeping components electrically and physically separated as much as possible. An example is to arrange for each unit which requires electrical power to be fitted with its own circuit protection device. If this is not done, two or more independent units will be sharing the same circuit protection device. When one of the units fail the circuit protection device will shut off electrical power to it. Unfortunately, when that happens, electrical power would also be shut off to the other unit(s). This situation describes a forced failure of a functioning, serviceable unit(s). A second example of forced failure, though non-electrical, is when an engine and a constant speed drive use the same lubricating system. Should the oil system fail, both the engine and the constant speed drive would be contaminated or denied of lubricant which could lead to extended failures. This forced failure would be avoided if the engine and constant speed drive use independent oil lubricating systems. A third example of the failure of one unit forcing the failure of a second is when electrical switches are mounted to hydraulic actuators. If the actuator seeps hydraulic fluid on the electrical switch, the switch may be rendered inoperable as switches are not designed to withstand the corrosive effects of hydraulic fluid. The recommended solution to this problem is to mount electrical switches and other electrical components so that they are not subject to hydraulic seepage.

A second way to improve reliability is to design components to match their operating environment. In illustration, let us review wire clamps. Though a seemingly insignificant item, if clamps used to anchor electrical wiring cables aren't physically and environmentally durable, the clamp will deteriorate with age and exposure. This will result in the cushion material lining the clamp to fall away exposing the wiring to chafing and subsequent electrical shorts through contact with the metal of the clamp. Another example would be transformer-rectifiers made of silicone wafers which don't adequately dissipate heat. Therefore, the transformer-rectifier overheats and fails when being used on the ground unless some form of forced ground cooling is provided. Yet another example is when critical electrical lines are routed through potential fire zones but are not hardened. An in-flight fire can quickly burn through these lines and eliminate the very systems designed to detect and deal with the emergency. A fourth instance exists when wire harnesses are routed through convoluted tubing. The tubing prevents chafing of the wire harness on other aircraft components; however, if the tubing does not provide adequate drainage, moisture will be trapped in the tubing. This will lead to moisture-induced, corrosion-related failures of the wiring with long exposure to the trapped moisture.

A third way to improve reliability is to conduct a thorough system analysis during design to anticipate as many potential failure modes as possible. In aircraft designed with three-phase electrical power generation and distribution systems, only one phase is monitored for possible failure. The loss of one of the other two phases will go undetected. This will result in the aircraft systems operating on two-phase power. This situation leads to a degradation of the systems and probable premature failure of components. Full consideration must be given to failure modes which can affect individual phases of a three-phase system. A second example is if voltage supply lines to line replaceable units (LRUs) are not provided with overcurrent protection devices, a short circuit in one of the LRUs may cause failure of the power supply. With the power supply out of commission, the other LRUs serviced by that power supply will also be lost.

Maintainability

Maintainability can be built into electrical systems and components in four different but primary ways:

1) Electrical systems should be designed in such a way the system is easier to troubleshoot.

2) Components should be kept separated as much as possible so failure of each component will be easy to fault isolate and remove and replace.

3) Components which require adjustment should be designed so the adjustment can be made quickly.

4) Components should be designed so repairs can be made easily and quickly.

Examples of these follow.

First, the maintainability of electrical systems will be improved if they are designed so they are easier to troubleshoot. The time required for troubleshooting electrical systems and components can be decreased if circuit breakers are grouped according to the system they support and their amperage. This would allow the technician to go to one system circuit breaker panel and determine at a glance if a circuit breaker is popped and what the amperage is. Troubleshooting times can also be reduced if wires are identified at frequent intervals so they can be easily traced. If this is not done, a technician could easily lose track of a wire he is tracing through a wire harness. A futuristic idea which would enhance troubleshooting would be to have power-indicating wire. This wire would have a coating which changes color when power is applied and reverts to normal when power is not applied.

Second, maintainability is enhanced if components are physically separated as much as possible so the components can more easily be fault isolated. Components which interact as a set, such as a generator and a constant speed drive, take more time to correctly determine which component is malfunctioning. More time is also required if the components must be built-up and bench checked prior to use as a set. Maintenance manhours and costs also increase when the "no defect" component of a set must be mated and tested with the serviceable replacement of the defective component. A second example of keeping components physically separated to ease fault isolation, and removal and replacement, is motors for fuel shut-off valves. If the motor can be treated independently of the valve assembly, then it is easy to determine which component is failing and remove it. Otherwise, like the generator and constant speed drive example, the motor and valve assembly will take longer to troubleshoot as a set, and will have similar maintenance for build-up and bench check, and for matching of replacements, as mentioned above for sets.

Third, maintenance times are decreased if necessary adjustments to components can be made quickly. A case in point is the relatively high degree of difficulty involved to adjust the constant speed drive basic speed governor on some aircraft. If the adjustment must be made from the bottom of the engine, the technician must somehow get underneath the engine to make the adjustment. Depending on the clearance beneath the engine, and on the size and dexterity of the technician, the technician may be able to kneel and reach up into the bottom of the engine. If not, he may have to almost bend backwards to get to the speed governor to make adjustments. The adjustment could be made more easily if the governor could always be adjusted from the side of the engine. The technician, in all likelihood, could stand and make the adjustment straight-on. An example where frequent rigging and adjustments might be eliminated altogether is when proximity switches are employed rather than mechanical switches. Proximity switches are of solid state construction with no moving parts and therefore require no adjustments. In comparison, mechanical switches incorporate cams, rollers, or levers, to activate the system. They require checks to see if the any of the moving parts need to be adjusted when the system indicates a failure.

Finally, fourth, maintainability is enhanced by simplifying the component maintenance procedures. One example of this is that repairs on electrical wires may be completed more quickly if the electrical wires can be crimped together instead of being soldered. Both connecting methods serve the same purpose but soldering takes more time and skill, and more support equipment. A second example is the maintenance manhours expended to remove components which are hardwired as compared to those which have quick-disconnect connectors. Components with quick-disconnect features can be removed in a matter of seconds and generally require no tools. Hardwired components take much longer and usually do require at least simple handtools.

Accessability

The last category, accessability, is probably the hardest for aircraft designers to "get their hands around" as it is not really assigned to any one engineering discipline in particular. Perhaps because of this accessability problems abound. For example, the accessability of the landing gear roller switches may be poor depending on where the switches are located inside the wheel well. Experience indicates that if the roller switches are attached to the landing gear doors, easier access to them will be obtained. Another example is the time it takes to remove and replace electrical LRUs. LRUs with wire harnesses which are mounted to terminal studs require a longer time to remove than LRUs with cannon plugs which feature a quick disconnect capability. Those components which require adjustments may obtain accessability if the technicians are provided easier access to the internal components which require adjustment or if they are provided external adjustment points. An example already cited is the constant speed drive basic speed governor adjustment. If the adjustment is made from the side of the engine, the maintenance procedure is easier to carry out than if the adjustment has to be made from beneath the engine.

Ongoing Initiatives

In an interview on 20 July 1987, Mr. Gary Evans, Advanced Tactical Fighter (ATF) Electrical Power Engineer, said that the ATF System Program Office is undertaking several initiatives in the reliability, maintainability, and accessability area. The ATF contractor(s) will incorporate proven high reliability parts into the first prototype aircraft(s). As the aircraft design evolves, the contractor(s) will consider new designs for various components provided reliability is not sacrificed. Each decision to switch to a new component will be preceded by a trade-off study addressing the reliability of the component(s) involved.

Mr. Evans pointed out that maintainability issues are being addressed such as the extensive use of built-in test to aid maintainers to troubleshoot. The ATF engineers are also reviewing existing data sources (such as the Lessons Learned abstracts) for information on how to increase reliability, and improve maintainability and accessability. Last but certainly not least, various program office personnel have taken advantage of Blue-Two visits sponsored by the Air Force Coordinating Office of Logistics Research (7). These visits allow government and contractor program office personnel to visit the maintenance units servicing items already fielded. From this trip, weapon system acquisition personnel are able to get firsthand exposure to various operational/maintenance constraints. This exposure will hopefully enlighten the weapon system designers and acquisition managers and make them more sensitive to reliability and maintainability problems so the same problems may be avoided in future weapon systems or acquisition efforts.

IV. PNEUDRAULIC SYSTEMS

Aircraft pneudraulic systems are comprised of a number of components (see Table IV, pg 10) that generate, distribute, and use energy in the form of fluid pressure. The primary function of pneudraulic systems is to transform the fluid pressure/energy to mechanical energy by interfacing with other aircraft system components.

Over the years problems have been noted with pneudraulic components which affect the reliability and maintainability of the components and the entire pneudraulic system. Some of these problems are inherent (designed into) to the pneudraulic component. Some are induced (introduced) by the interaction of the pneudraulic component with other aircraft systems.

This thesis is a managerial document which reviews both inherent and induced pneudraulic component problems which affect the reliability and maintainability of the components and the system. It also proposes corrective actions to the problems. A compilation of problems was obtained from three sources. The three sources are 1) the Air Force Lessons Learned data bank, 2) interviews with pneudraulic technicians from the 906th Tactical Fighter Group, and 3) interviews with pneudraulic technicians from the 4950th Test Wing. All three sources reside on Wright-Patterson Air Force Base, OH.

The results of the literature review and the interviews are contained in Appendix F, Pneudraulic Components. Appendix F presents problems experienced with the pneudraulic components and potential corrective actions for each problem. The problems, 70 in all, may be collected in three broad categories: Reliability, Maintainability, and a subset of maintainability, Accessability. The following paragraphs summarize the component categories. For further information, see Appendix F.

Reliability

The reliability of pneudraulic components and pneudraulic systems can be improved two ways:

1) Components should be kept hydraulically and physically separated as much as possible. If the separate entities of each component are retained, the failure of one component will not affect the function and reliability of a second.

2) A thorough system analysis of each system and its embedded components should be conducted during design to identify as many failure modes as possible. Anticipation of the various failure modes will permit design and system engineers to design reliability into the components, parts, and system.

Examples of these follow.

The first way to improve reliability is by keeping components and systems pneudraulically and physically separated as much as possible. An example is to arrange for each pneudraulic unit to be fitted with its own fuse. If this is not done, two or more independent units will be sharing the same protection device. When one unit fails the fuse will shut off pneudraulic fluid to it. Unfortunately, when that happens, pneudraulic fluid is also shut off to the other unit(s). This situation describes the forced failure of a functioning, serviceable unit(s). Another example, though non-pneudraulic, is if primary and redundant pneudraulic pumps are driven from the same drive component. The possibility of total pneudraulic system failure rests with the reliability of the drive component. Should the drive shaft or one component in the drive system fail, a forced failure will occur in the pneudraulic system. A third example of the need to keep systems separated is an aircraft mishap which determined that pneudraulic lines and electrical wiring were routed in too close proximity. As a result of chafing, the wiring arced and weakened the wall of a high pressure hydraulic line. The line ruptured, allowing hydraulic fluid to escape. Arcing from the chafed wire ignited the fluid and caused a fire.

The second improvement area for reliability is to conduct a thorough system analysis during design to anticipate as many failure modes as possible. A case in point is the pressurization of hydraulic reservoirs. Reservoirs are normally pressurized on the ground with support equipment. In the event of reservoir pressure loss, usually through failure of the pressure relief valve, the engine bleed air system will pressurize the reservoir through a shuttle valve. If this pressurizing air flow is sustained for a long period the heat from the engine bleed air could damage the tubing and flex lines in the reservoir pressurizing system. A second example is that aircraft incorporating nonseparated-type pneudraulic reservoirs may experience hydraulic failure if the moisture removing elements within the bleed air components fail to remove all contaminants. Moisture introduced into the pneudraulic system may freeze at altitude and induce a component failure. Another example is when pneudraulic lines are subjected to stress and vibration, the lines will eventually weaken and fail over time if they are not adequately supported. Bracing and shock mounting the lines will control the affects of stress and vibration.

Maintainability

Maintainability can be built into pneudraulic systems and components four different ways:

1) Pneudraulic systems should be designed so the system is easier to troubleshoot.

2) Components should be kept separated as much as possible so failure of each component will be easy to fault isolate and remove and replace.

3) Components should be structured so improper installation cannot occur.

4) Pneudraulic systems should be designed so servicing of the system can be completed easily and quickly.

Examples of these follow.

First of all, maintainability would be improved in pneudraulic systems if troubleshooting aids were designed into the system. An example is if manual shutoff valves are placed at intervals throughout the pneudraulic system to isolate the various components. By isolating components, technicians will be able to take direct input and output pressure readings of components without fluctuations being introduced by other pneudraulic components. Isolating components also allows the technician to remove a component without having to drain a large part of the pneudraulic system. He can shut off fluid flow before and after the component so that he just has to extract fluid from the component in question. A second idea which would speed the troubleshooting of pneudraulic systems deals with pneudraulic filters. Filters are routinely checked for contamination. This procedure is not hard to do yet it requires removing the filter for examination. If the filter were housed in a clear bowl, visual checks could be performed which would reduce maintenance times.

Secondly, maintainability is enhanced if components are separated as much as possible so failure of each component will be easy to fault isolate and remove and replace. An example where the integration of components and systems complicates maintenance is when slat and flap systems are integrated. On one aircraft the slat system is coupled to the flap system and is automatically controlled by flap actuation. Power for operation of the slats is provided by the flap and slat drive gearbox. Output of the gearbox is transmitted by torque tubes through a decoupler unit and then to a clutch and brake assembly. From there, the power output is transmitted by torque tubes to the slat drive actuators in the wings. Making the slat system independent from the flap system would decrease the complexity of the system. System independence would make it easier to isolate slat problems and facilitate troubleshooting, repair, and rigging of the system.

Third, components should be structured so improper installation could not occur. A case in point is pneudraulic fuses. Fuses have decals on them indicating installation direction but they can still be installed backwards. This situation could be avoided one of three ways: If the fuses were designed so that they could only be hardmounted in one direction; If the input and output fittings were different sizes; Or, if the fittings were color coded so that the technician only had to match up colors. A similar situation is encountered with look-alike servicing valves. If the valves are not clearly identified, inadvertent connection to the wrong pressure may occur. A differentiation of the valves either by color code or physical shape will prevent this from happening.

Designing pneudraulic systems so servicing of the system can be completed easily and quickly is the fourth way to improve maintainability. Pneudraulic system servicing procedures require operating the bleed valves several times while servicing the system. If the bleed valves and reservoir gauges are not located in close proximity, this procedure will have to be carried out by two people. This increases servicing times and increases manpower requirements. If the pneudraulic system bleed valves and reservoir gauges are located in close proximity, servicing and bleeding the system could be accomplished by one person. Likewise, each reservoir should have its own quantity gauge in addition to the system indicator in the cockpit. This will prevent attempting to service reservoirs which do not require it.

Accessability

As stated in Chapter III, the last category, accessability, is probably the hardest for aircraft designers to "get their hands around" as it is not really assigned to any one engineering discipline in particular. Yet, accessability problems abound. Accumulators on one cargo aircraft, though a low failure item, are difficult to get to. To perform maintenance on the accumulator, the hydraulic reservoir and several hydraulic lines must be removed. On one particular fighter, approximately 16-20 manhours are required to remove a speed brake actuator attachment bolt. To remove the bolt both ejection seats and the actuator cover located between the right position rudder pedals must be removed first. Since the rudder pedals are under the instrument panel, there is very little working space and the removal of the actuator cover attaching screws is a very time-consuming process. Servicing access problems can also crop up if the minimum and maximum load characteristics are not taken into consideration during the design of the aircraft. An example is the alternate landing gear extension system on a particular fighter aircraft. This pneudraulic system is serviced through a charging valve located in the main landing gear wheel well. Normally, the valve is easy to reach. However, the valve becomes inaccessible when the aircraft is fully loaded. When fully loaded the airframe sits so low that the right main landing gear strut will not allow enough clearance to hook up the service hose. If any of the emergency systems linked to the common valve requires servicing, the only way to gain access is to pump up the struts to full extension and then readjust the struts after servicing. If this valve were located a few inches forward of its present location, the interference problem would not exist.

Ongoing Initiatives

In an interview on 3 August 1987, Mr. Bill Kinzig, Advanced Tactical Fighter (ATF) Lead Flight Equipment Engineer, said that the ATF contractor(s) are basing the design of the pneudraulic systems on existing reliability and maintainability data. In the reliability area, the contractor(s) are reviewing current failure data on fighters already fielded. From this data, the design engineers will try to improve reliability by designing out various failure modes. After the system is designed then it will undergo extensive qualification testing.

Mr. Kinzig said the same approach is being undertaken to improve the maintainability of the pneudraulic systems. The contractor(s) will review existing maintainability data to select those areas where improvement can be made. Once identified the design engineers will also try to improve the maintainability of the system. One example that he gave is the use of self-diagnostics to monitor fluid levels (11).

V. CONCLUSION

The goal of this thesis was to compile a management document containing suggestions to improve the design of electrical and pneudraulic systems and their related components so that reliability will be increased and maintainability will be improved. Overall, the goal was accomplished but much remains to be done to improve R&M for aircraft systems. Listed in Table VI are seven related areas recommended for further investigation.

The bottom line is that system and component designers need to constantly question: 1) In what ways can this system/component be made more reliable? and 2) How can the system/component be made easier to maintain? Sometimes the answers may conflict. In that case, trade-offs will have to be made between reliability and maintainability. A good common sense guide to follow is: The lower the reliability of a component, the easier it should be to get to it and maintain it.

Designers are cautioned not to think they are the ultimate authority of a system or component. There are thousands of technicians turning the screws on weapon systems everyday who can provide valuable input into the design of systems based on their "real-world" experiences. Designers and engineers should not be hesitant to ask these technicians their opinions. Those opinions should become another valuable data point from which to work. An excellent way to gain this information, and some actual weapon system experience, is through "Blue-Two" visits sponsored by the Air Force Coordinating Office of Logistics Research, AFALC/AFCOLR, Wright-Patterson AFB OH. These visits allow weapon system acquisition personnel, both government and contractors, to visit the maintenance units of items already fielded. From this trip, they are able to get firsthand exposure to various operational/maintenance constraints. With this knowledge, they should then be able to design more reliability and maintainability into the systems they are working on. If a Blue-Two visit can not be arranged, designers should initiate contact with maintenance units themselves. All it takes is a few phone calls to be placed in touch with the technicians maintaining the systems.

It is also recommended that designers tap into the extensive lesson learned data bank at the Air Force Lessons Learned Office, AFALC/LSL, Wright-Patterson AFB OH. The data bank contains validated lessons learned that have been submitted by technicians and acquisition personnel throughout the government. The Lesson Learned office can conduct keyword searches on any subject. They will then provide a printout of everything in their files on the subject. Each printout will contain a description of problems encountered and recommended corrective actions.

Table VI

AREAS FOR FURTHER INVESTIGATION

1. Results of the proliferation of non-standard parts. What impact does the proliferation of non-standard parts throughout the Air Force (the Department of Defense) have on the maintainability of weapon systems? How does it impact component spares costs and stock levels? Is reliability sacrificed? How does it affect unit ability to deploy weapon systems? What can be done? What should be done?

2. Consequences of vague technical orders. How are technical orders considered vague? How does this hamper technicians in carrying out their jobs? What action(s) is necessary?

3. Advantages of user participation in system acquisition. Within the past five years, system acquisition has been opened to senior non-commissioned officers. How effective has this been? What have been the advantages and/or disadvantages of doing this?

4. Results of the proliferation of support equipment. As with non-standard parts, there has been a proliferation of support equipment in the Air Force. How has this impacted our warfighting capability? Is this proliferation justified? What can be done? What should be done?

5. Results of a failure to properly assign work unit codes. If work unit codes are not broken out in sufficient detail then items which need repair will be charged against the next higher assembly. How does this bias the maintenance data collection? How does it affect the design of weapon system components? What should be done?

6. Reliability/maintainability trade-off guidelines. R&M trade-offs are made constantly. Can a set of standard guidelines be assembled to assist acquisition personnel in conducting and analyzing trade-offs?

7. Time change items vs replace only on failure. The old maintenance adage is, "If it isn't broke, don't fix it." There are many components on weapon systems which violate this adage since they are designated as time change items. Would the reliability of weapon systems be decreased if we replaced only on failure? Would the stock level of parts change? What are the advantages and disadvantages of each method? What should be done?

Appendix A

Interview Questions

Assume you are an electrical/pneudraulic consultant for a defense contractor. What would you want to tell the contractor about how to design component ______________? More specifically, what could be done to increase the reliability and maintainability of the component?

Accessability

1. How easily can the maintenance technician gain access to the high-failure items? What limits access?
2. How easily can the maintenance technician access items that do not have high failure rates? What limits access?
3. Can the component be accessed by one person?
4. How can access of the component be improved?

Maintenance Tasks

5. How easy is it to fix the high-failure items? What limits ease of maintenance?
6. How easy is it for the maintenance technician to maintain the items that do not have high failure rates? What limits ease of maintenance?
7. Can the component be maintained by one person?
8. Is each component a stand-alone item, i.e., does maintenance on one item automatically require maintenance on another item(s)?
9. Which components are the hardest to maintain and why?
10. How can the maintainability of the component be improved?

Troubleshooting

11. When you troubleshoot the component, can you do it alone or do you need assistance from other specialists?
12. Do you need special test equipment to conduct your troubleshooting on the component?

Failure Analysis

13. What breaks or fails the most often? For what reason?
14. Which components are the least reliable and why?
15. How can the reliability of the component be improved?

Design

16. Conceptually, is there a way that functions of several components can be combined thereby eliminating the requirement for so many individual components?
17. Is there a simpler way to perform these functions?
18. Is this component's function performed by another component, perhaps in something other than aircraft?
19. If the function is duplicated by another component, can the component be adapted for use in aircraft?

Appendix B

Interview Question Validation

The interview questions used in this research were validated by the following individuals.

Lt Col Paul Reid
Instructor of Logistics Management
Air Force Institute of Technology

Lt Col David Lloyd
Assistant Professor of Logistics Management
Air Force Institute of Technology

Major Phillip Miller
Assistant Professor of Logistics Management
Air Force Institute of Technology

Mr. Hannibal Davis
Pneudraulic Shop Chief
4950th Test Wing

Mr. Robert Neeley
Electric Shop Chief
4950th Test Wing

Ms. Sandra Simmons
Program Manager
B-1B Program Office

Appendix C

Electrical Components Definitions

Circuit Protection Device-A contrivance built in such a way that when current flow exceeds a set amount the contrivance automatically fails thereby opening the circuit (3:85-86).

Constant Speed Drive-A hydraulic mechanical transmission which converts variable engine speed input to a constant rpm output to drive an alternating current generator (4:64).

Control Device-A switch which opens and closes an electrical circuit (3:83).

Frequency and Load Controller-A device which monitors the frequency and electrical load of a generator and balances out any deviations via the constant speed drive.

Generator-An apparatus which generates the electrical energy for the system.

Hardware-The screws, nuts, bolts, fasteners, and safety devices used to connect various electrical components to one another and to the aircraft.

Motor-A machine which transforms electrical energy into mechanical energy (4:90).

Relay-An electrically energized, or mechanical, latch device used to complete an electrical circuit.

Transformer-Rectifier-A device which changes alternating current to direct current (4:82).

Variable Resistor-A device which will vary the voltage to an operating unit within a given range of values (3:84).

Vibrator-A unit which changes 28 volts of direct current into pulsating current (5:45).

Voltage Regulator-A unit which maintains a constant output voltage under varying load conditions (4:38).

Wiring-A metallic rod used to transport electrical current.

Appendix D

Pneudraulic Components Definitions

Accumulator-A storage chamber for gas or fluid under pressure. It aids or supplements the power pump when several pneudraulic mechanisms are in operation at the same time. It provides limited operation of a pneudraulic mechanism when the power pump is not operating. It dampens surges in the pneudraulic system (14:30).

Actuator-A unit which converts hydraulic or gas pressure to mechanical movement to do the required work (14:33).

Filter-A device installed in a system to remove foreign particles from fluid or air (6:22).

Fittings-Pneudraulic connectors for linking various components to each other.

Fuse-A contrivance built so that when fluid or gas flow exceeds a set amount the contrivance automatically fails thereby closing off the flow.

Hardware-The screws, nuts, bolts, fasteners, and safety devices used to connect various pneudraulic components to one another and to the aircraft.

Pressure Regulator-A unit which maintains system pressure between two designed pressure limits (6:11-12).

Pressure Switch-An electrical switch which opens and closes the circuit to electrically driven pumps to maintain system pressure within set limits (6:34).

Pump-A mechanical device which produces fluid or gas under pressure to the actuating components (14:17).

Reservoir-The pneudraulic fluid storehouse for a system. It contains enough fluid to supply the normal operating needs of the system as well as an additional supply to replace fluids lost through minor leakage (14:11).

Seals-Devices used to confine fluid or air in tubes or pipes (14:8).

Tubing-Pipes and hoses through which hydraulic fluid or air is transported between the various pneudraulic components.

Valve-A device which directs the flow of fluid or gas in the proper direction to control the converting of fluid or gas into mechanical movement (14:36).

Appendix E

Electrical Components

The following pages contain a list of problem areas and suggested corrective actions for the electrical components under review. This list was compiled from four sources. The source for each problem and corrective action is cited by a code. The code is:

LLXXXX — Information extracted from the lessons learned data bank at AFALC/LSL, Wright-Patterson AFB OH. There is a four digit number following the LL. That number is the reference number assigned by the lessons learned office.

LRX:X-X — Information extracted from the Air Force Coordinating Office for Logistics Research "brown books" at Wright-Patterson AFB OH. The first number following the LR is either a 1, 2, or 3 which corresponds to the volume the information is extracted. The number after the semicolon is the reference number assigned by the logistics research office.

906TFG — Information arising from an interview with some of the electricians assigned to the 906th Tactical Fighter Group at Wright-Patterson AFB OH. The interview occurred on 22 May 1987.

4950TW — Information arising from an interview with some of the electricians assigned to the 4950th Test Wing at Wright-Patterson AFB OH. The interview occurred on 27 May 1987.

Index of Components by Category

Component	Reliability	Maintainability	Accessability
Circuit Protection Devices	LL0073, LL0410 LL0630, LL1332 LL1418, LL2038 906TFG-3	LL2025, 4950TW	LL0210, LL0899 906TFG-1 & 2
Constant Speed Drive	LL0782	LL0084, LL0134 906TFG-1 & -2 4950TW	LL0795
Control Devices	LL0703, LL0817 LL1427, LL1459	LL1133, LL1968	906TFG, 4950TW
Generators	LL0101, LL0761 LL1054, LL1184 LL1989	LL0134 906TFG-1 & -2	4950TW
Hardware	LL0035, LL0409 LL0846		LL0371, LL0626 906TFG
Motors	LL1054	LL0651	LL0760
Relays	LL2021	LL0402, 906TFG	LL0163, LL0393
Transformer-Rectifier	4950TW		906TFG
Variable Resistor	906TFG		4950TW
Voltage Regulator	906TFG		4950TW
Wiring	LL0011, LL0172 LL0401, LL0416 LL0720, LL0764 LL0792, LL0818 LL0844, LL0905 LL1055, LL1085 LL1193, LL1234 LL1298, LL1429 LL1531, LL1555 LL1560, LL1565 LL1605, LL1606 LL1911, LL1916 LL1956, LL1962 906TFG-1 & -2 4950TW-1 & -2	LR1:3-142 LR3:3-4, LL0106 LL0111, LL0167 LL0176, LL0839 LL1208, LL1220 LL1905, LL1910 LL1912	LL0075, LL0371 LL0376, LL0581 LL0811

No findings for Frequency and Load Controller and Vibrator.

Circuit Protection Devices (CPD)

Source	Problem	Corrective Action
LL0073	two or more independent units that draw electrical power through a common CPD can cause unnecessary loss of power to operable units when a single unit fails thereby tripping the CPD	all units should be separately protected to provide maximum operational reliability
LL0210	CPDs internal to LRUs increase maintenance times	CPDs should be accessible from outside of LRUs
LL0410	an accident potential exists whenever warning lights and the system(s) they are intended to monitor are protected by the same CPD	warning devices should be designed with a power source independent of the CPD of the system being monitored
LL0630	if voltage supply lines are not provided with a short circuit may cause total system failure because of subsequent power supply burnout	CPDs should be required on all CPDs, voltage supply lines so that a short circuit in one unit doesn't lead to complete system shutdown
LL0899	maintenance times will increase if the CPDs are easily accessible	CPDs should be located to assure not simple and easy replacement
LL1332	failure to provide CPDs in electrical flight control systems while operating from emergency power could cause total loss of flight control	include CPDs in the design on electrical flight control systems to disconnect electrical power from the flight control system inverters if, during emergency power operation, an overvoltage condition occurs

LL1418	with a step down transformer, protection of the higher current in the secondary circuit must be provided	decrease the size of the CPD in the primary circuit or install CPDs in the secondary circuit
LL2025	aircraft CPDs with faded or illegible amperage ratings pose a problem for maintenance personnel in trying to determine the size of the CPD	amperage rating markings should be as permanent as the normal life expectancy of the CPD
LL2038	several systems can be lost if they are controlled by the same CPD	each system and its backup or emergency system should have separate CPDs
906TFG-1	CPDs on the F-4 don't take long to maintain but sometime require as many as four different equipment specialists to access them	greater thought needs given to location of CPDs in aircraft
906TFG-2	CPDs in F-4 cockpits can only be accessed from inside the cockpit as there is no access via an access panel on the outside of the aircraft	provide a plug-in CPD with a quick disconnect
906TFG-3	when F-4s are not pressurized, water can get inside the cockpit and the CPDs	hermetically seal the CPD
4950TW	when troubleshooting electrical circuit problems in cockpits, additional time is spent finding the related circuit breaker(s)	consider 1) grouping circuit breakers by the system they support, 2) grouping circuit breakers by amperage, and 3) color-coding the breakers by amperage

Constant Speed Drive (CSD)

Source	Problem	Corrective Action
LL0084	CSD oil servicing is critical and small changes in aircraft attitude can result in error readings	design of CSD oil systems should use an oil indicator system which is not sensitive to minor attitude changes
LL0134	maintenance time is wasted if generators and CSDs have to be removed and replaced together	system specifications should require fault isolation and removal/replacement capability for individual LRU components without removal of associated components
LL0782	CSDs mounted in engines and using the engine oil can be contaminated should the oil unit fail	CSDs should have independent oil systems
LL0795	some CSDs cannot be easily accessed	ensure accessability is built-in to reduce the amount of time spent doing routine maintenance
906TFG-1	on an F-4, the CSD and generator have to be removed as a unit (see LL0134 also)	design the CSD and generator interface so they can be removed separately
906TFG-2	on an F-4, four specialists are needed to assist in the trouble-shooting of the CSD	easier trouble-shooting procedures requiring fewer people need to be developed
4950TW	adjusting the basic speed governor is difficult if the adjustment must be made from underneath the engine	redesign/relocate the basic speed governor so the adjustment can be made from the side of the engine

Control Devices

Source	Problem	Corrective Action
LL0703	electrical switches mounted directly to hydraulic actuators may allow seepage of hydraulic fluid into the switch	switches and other electrical components should not be mounted where they are likely to be subjected to hydraulic seepage
LL0817	without limit sensors and asymmetry sensing devices on flights controls, control surfaces and components can be damaged	sensor switches and asymmetry systems for flight control surfaces should be required
LL1133	mechanical switches require frequent rigging and adjustments	proximity switches should be used as often as possible
LL1427	control switches that don't remove complete power from the system can present a safety problem	control switches must remove all power from equipment related to that circuit
LL1459	improper design and application of proximity switches in landing gear systems will result in mishaps	the environment in which the switches will be used must be considered during design and the design must be completely field tested prior to production
LL1968	ambiguous labeling of switches could result in mishaps (this has happened with canopy release controls)	ensure proper labeling of all switches
906TFG	on an F-4, the control devices don't take long to maintain but they are sometimes difficult to access	greater thought needs given to access of the control devices
4950TW	accessability of landing gear roller switches may be difficult depending on their location inside the wheel wells	recommend locating the roller switches on the landing gear doors

Generators

Source	Problem	Corrective Action
LL0101	loss of one phase of a three-phase power source can go undetected	system design must consider failure modes that can affect individual phases of a three-phase system
LL0134	maintenance time is wasted if generators and constant speed drives have to be removed and replaced as a unit	system specifications should require fault isolation and removal and replacement capability for individual components without removal of associated components
LL0761	greases used in generator packs are often inadequate for the high speed generator rotational movement	bearing packs should use grease conforming to MIL-G-81322
LL1054	when redundant accessories are driven from one common drive component, the possibility of total system loss lies in the strength of that one drive component	redundant drive sources should be required
LL1184	CSD generators have a low mean time between failure	variable speed constant frequency generators should be considered in place of the CSD type
LL1989	use of MIL-L-7808 oil in a magnesium case coated inside with sodium di-chromate can cause a breakdown of the coating thereby creating a sludge which plugs the filter to the oil cooling system and results in a pressure and temperature increase until automatic ignition occurs	environmental characteristics must be considered when incorporating MIL-L-7808 oil

906TFG-1	on an F-4, the CSD and generator have to be removed as a unit (see LL0134 also)	design the interface of CSD and generator so they can be removed separately
906TFG-2	on an F-4, four specialists are needed to assist in the trouble-shooting of the CSD	easier trouble-shooting procedures requiring less people need to be developed
4950TW	removal and replacement of generators is slowed down as time is spent connecting and disconnecting terminal wiring	consider using quick disconnect electrical leads on generators

Hardware

Source	Problem	Corrective Action
LL0035	fastener recess designs not compatible with the maintenance environment and location result in excessive manhours for removal and replacement	fastener designs selected must be the optimum for the environment and location
LL0371	replacement of electrical LRUs is difficult and time-consuming when quick disconnect is not possible and soldering or unbolting of connections is required	all electrical system LRUS should have quick disconnect capability
LL0409	failure to verify that safety devices for switches and controls are completely reliable can result in a safety hazard	all safety devices specified must be reliable and safe
LL0626	removal and replacement of components fastened by bolt and nut or by screw and nut is difficult	consider using captive nuts as a means of fastening removable components and panels
LL0846	clamps have to be replaced if they deteriorate with age and exposure	clamps must be installed in the proper environment and should be durable
906TFG	safetying devices consume a large amount of time in the maintenance of electrical equipment	consider using cotter pins or self-locking nuts on equipment that requires a lot of maintenance

Motors

Source	Problem	Corrective Action
LL0651	sometimes motors and related components must be replaced as a unit which leads to higher maintenance manhours	motors and its related equipment should be independent of each other
LL0760	many manhours are wasted by unsealing/resealing cases and removing components for adjustment	provide easy access to internal components that require adjustment or provide external adjustment of internal components
LL1054	when redundant accessories are driven from one common drive component, the possibility of total system loss lies in the strength of that one component	redundant drive sources should be required

Relays

Source	Problem	Corrective Action
LL0163	inadequate access to components cause unnecessary manhour expenditure	components requiring frequent access should be located with direct access
LL0393	equipment access for maintenance may be impaired by various alternate mission equipment configurations	equipment access should be taken into consideration when designing mission equipment
LL0402	hardwired relays are difficult and time-consuming to fault isolate and replace when they fail	maintenance repair times should be considered when deciding between wiring vs connector installed components
LL2021	when systematic analysis for hidden circuits is not performed during the design process, unplanned functions may occur in complex electrical equipment	completely analyze electrical circuitry for hidden circuits
906TFG	on an F-4, relay panels are a high failure item and are hard to access and maintain	suggest going to a plug-in type relay and relocate them for ease of maintenance

Transformer-Rectifiers (TR)

Source	Problem	Corrective Action
906TFG	on the F-4, the TR is a low failure item but hard to access when it does fail (under the seat); fortunately you can troubleshoot from the cockpit prior to removing the seat	consider a better location even for low failure items or easier access if it must stay in current location
4950TW	TRs made of silicone wafers don't adequately dissipate heat and therefore overheat when being used on the ground; this is not an in-flight problem as the cooling pack then provides additional cooling	the design of TRs must consider every environment in which the TR will operate

Variable Resistors

Source	Problem	Corrective Action
906TFG	the variable resistors on F-4s are easy to access but they have a high failure rate due to the wearing out of the aluminum brush on the resistor	research needs to be conducted to minimize the wear rate on the aluminum brushes; replace it with a new design or use something in place of an aluminum brush
4950TW	on the T-39 the variable resistor is a low failure item but hard to access when it does fail (under the seat)	consider a better location even for low failure items or easier access if it must stay in the current location

Voltage Regulators

Source	Problem	Corrective Action
906TFG	the voltage resistors on F-4s have a high failure rate but they are easy to troubleshoot and remove and replace	investigate the high failure component(s) on the voltage regulators and solve their problems
4950TW	removal and replacement of voltage regulators can be slowed down based on the mounting and wiring configuration of the regulator	use slide-in racks and cannon-plug connectors for the mounting and wiring configuration of voltage regulators

Wiring

Source	Problem	Corrective Action
LR1:3-142	many hours are spent troubleshooting electrical problems and trying to determine what is/is not getting power	develop power indicating wire: perhaps wire whose coating changes color when power is applied
LR3:3-4	much effort is spent maintaining connectors, however little guidance is given on preventive maintenance	devise a military handbook listing guidelines for connector preventive maintenance
LL0011	connectors without strain relief devices could result in pins, or wire and pins, pulled out of connectors	connectors must be designed with strain relief devices to match the environment and probable maintenance handling
LL0075	poor accessability to wiring leads to high maintenance manhours and support costs	wiring should be routed where technicians can gain easy access to it
LL0106	the wiring and connectors of units frequently removed are subject to added damage via wear and tear	design electrical hookups that can be rapidly and simply connected/stowed with a minimum of damage
LL0111	designs which require cutting and splicing of wiring for component replacement cause excessive failures, false alarms, and unnecessary downtime	designs should require installation and removal of components/parts without cutting wires
LL0167	wiring running to various components without slack built-in often results in damage to the wires and/or connectors (see LL0111)	designs should allow adequate slack for item removal
LL0172	the size and length of wire in wiring harnesses is inadequate and causes equipment breakdowns	designs should address the problems of wire size and length

LL0176	proliferation of nonstandard cable/wiring and connectors increase support costs and maintenance manhours	standard cables/wires and connectors should be used as often as possible
LL0371	replacement of electrical LRUs is difficult and time-consuming when quick disconnect is not possible and soldering or unbolting of connections is required	all electrical system LRUs should have quick disconnect capability
LL0376	when LRUs have subassemblies or modules that require unsoldering/soldering for removal and replacement, maintenance man-hours required for the LRU repair are higher and soldering heat can impact reliability	LRUs should have modules and subassemblies that have quick disconnect features
LL0401	frequent handling of wiring harnesses result in broken wires and excessive downtime for maintenance	wiring harnesses should be located to require infrequent movement or handling to avoid these induced failures
LL0416	an in-flight fire can burn through lines and negate the systems	wiring routed through potential fire zones must be hardened
LL0581	failure to locate electrical connectors with adequate clearance and easily accessible without removal of equipment will result in excessive maintenance time	connectors must be in easily accessible locations
LL0720	sharp corners and edges on LRUs chafe the insulation of electrical cables	route wires so they do not chafe on LRUs; soften all edges and corners
LL0764	wire bundles and their related systems have failed when rubbed by moving parts	route wires to provide adequate clearance from moving parts

LL0792	in an effort to save weight, light-weight wiring is sometimes used which can result in maintenance problems due to fatigue cracks of the wiring	ensure that reliability is not sacrificed in a weight-saving plan
LL0811	some components have limited accessability and pose a maintenance problem when trying to work on them	ensure components are provided adequate accessability
LL0818	the use of aluminum wiring for electrical power systems can result in serious failures and fires	don't use aluminum wiring
LL0839	many wire bundles do not have adequate equipment interface identification near the ends	design specifications should require MIL-W-5088H para 3.9.4 be followed; "...band shall bear the P and J number identification...and the equipment nomenclature."
LL0844	aircraft fires can occur when electrical wiring and tubing carrying hydraulic fluid, fuels, or gases are routed in close proximity or clamped together	wiring must be routed separately from other systems
LL0905	safety hazards can result when uncoated, wire braided cable harnesses unravel	exposed wire braided cable assemblies should be coated
LL1055	inflexible wiring harnesses attached to units that require movement may promote failures due to broken or cut wires	wiring harnesses should accommodate the full range of travel of units they are connected to
LL1085	due to the operating environment, vibration, and stresses that are peculiar to airframes, wiring and connectors are more prone to breaking, chafing, becoming brittle, etc.	special attention is required in the selection of electrical wire and connectors

LL1193	connectors designed with soft metal alignment pins do not have a high mean time between failure	connectors should be designed so that the metal used in the alignment keys is at least as durable as the metal used in the connectors
LL1208	soldering connectors lowers reliability and increases maintenance times on the cables	crimping instead of soldering should be used when possible
LL1220	failure to identify individual wires in wire harnesses at frequent intervals cause excessive troubleshooting time	wires should be easily traceable throughout an aircraft
LL1234	wires and harnesses that run through convoluted tubing could be exposed to constant moisture which in turn enhances corrosion	moisture must not be allowed to build up in wiring tubing or conduits; drainage points could be one solution
LL1298	electrical units will fail if water is allowed to enter the connectors thereby causing a short	connectors must be properly sealed to prevent moisture entry
LL1429	fuel pump electrical connectors not properly designed and sealed could promote a fuel tank fire or explosion	fuel pumps should include the following design criteria: 1) a connector consisting of a single piece insulator (insert) and properly spaced contacts and 2) complete sealing of both pump (wet) and conduit (dry) side wiring contacts with fuel resistant potting and top coat compounds

LL1531	anti-static additives can cause a breakdown in electrical connector seals	better sealing of connectors must be effected before the use of an antistatic additive can be approved for operational use
LL1555	use of polymide insulated wires exhibit flashover characteristics which may lead to premature replacement	do not use polymide insulated wire
LL1560	locating electrical connectors close to high vibration-producing accessories results in fretting of the connector pins and subsequent failure of the connector	connectors must be installed away from high vibration accessories
LL1565	close proximity of electrical terminals and the use of screws to tighten leads will allow arcing if terminals are bent or lead attachments are loose	terminals should be designed to prohibit arcing between terminals by the use of adequate spacing, protective barriers, insulation on exposed metal surfaces, and use of bayonet-type fasteners
LL1605	when aluminum electrical connectors are coated with electroless nickel, the connectors are more susceptible to corrosion	cadmium coatings should be used except in high temperature environments
LL1606	use of bright tin plating on electronic component leads may cause tin whisker growth which can result in the shorting out of electronic circuitry	use tin alloy containing 1-3% lead or antimony or an electro-deposited solder

LL1905	identification codes on lug-terminated wire harness leads deteriorate, causing inadvertent cross-connection of leads which may not be detected until operational checks are performed	design lug-terminated wire harnesses to reduce the possibility of cross-connecting wires
LL1910	electrical connectors allowed to hang loose an electrical shock hazard and/or damage to connectors	provide dummy receptacles or stowage provisions for electrical connectors not always connected in flight
LL1911	moisture and contaminants reduce the reliability of electrical systems and promote corrosion (also see LL1298)	aircraft designs must prohibit the ingestion of moisture and/or contaminants into electrical bays
LL1912	identical connectors used in adjacent areas invite inadvertent cross-connecting of the wrong plug to the wrong unit	avoid the use of identical connectors in adjacent areas
LL1916	when all contacts are not installed in crimped contact electrical connectors, the installed pins bend during connector mating	ensure all contacts are installed on crimped contact connectors
LL1956	damage to cables and connectors results when chafing or strain occurs during maintenance	cables must be installed in a manner to preclude strain and chafing
LL1962	locating electrical cables and wire bundles in areas that exceed the maximum conductor temperature causes damage to the cables and connectors	electrical cables and wire bundles must be designed for protection from high operating temperature damage

906TFG-1	on F-4s, wiring is a high failure item probably due to maintenance, i.e, the wiring harness to a component has to be pulled on to gain access to the cannon plug for connection and disconnection and it has to be folded back out of the way of other items when the component is disconnected (see LL0011)	two possible suggestions: place wiring on a take-up reel or have a basic piece of wiring as an integral part of the aircraft with a female cannon plug then have each electrical component have (say) a foot long "pony-tail" wiring harness with a male cannon plug
906TFG-2	when electrical wiring and hydraulic components are routed close to each other, hydraulic fluid will inevitably leak on the wiring and promote failure	route wiring and hydraulic components separately or use wiring insulation/ materials that are compatible with hydraulic fluid
4950TW-1	the slightest damage to an electrical wire can cause intermittent or complete failure of a system	design electrical power material based on fiber optics properties which is highly flexible and can still function despite a break in the line
4950TW-2	the round design of wiring consumes a lot of space	consider using tightly spaced, square wires

There are two components for which no problems or recommendations were proposed. These components are

1. Frequency and Load Controller

2. Vibrator

Appendix F

Pneudraulic Components

The following pages contain a list of problem areas and suggested corrective actions for the pneudraulic components under review. This list was compiled from three sources. The source for each problem and corrective action is cited by a code. The code is:

LLXXXX Information extracted from the lessons learned data bank at AFALC/LSL, Wright-Patterson AFB OH. There is a four digit number following the LL. That number is the reference number assigned by the lessons learned office.

906TFG Information arising from an interview with the pneudraulic chief assigned to the 906th Tactical Fighter Group at Wright-Patterson AFB OH. The interview occurred on 9 June 1987.

4950TW Information arising from an interview with some of the pneudraulic specialists assigned to the 4950th Test Wing at Wright-Patterson AFB OH. The interview occurred on 2 June 1987.

Index of Components by Category

Component	Reliability	Maintainability	Accessability
Accumulators	LL0731, LL0933		4950TW
Acutators	LL0092, LL0965 LL1180, LL1599	LL0812	LL0613
Filters	LL1432	LL1080, 4950TW	906TFG
Fittings	LL0395, LL0858 LL1408, 906TFG		LL0581, LL0582 LL0881
Fuses	LL0073, LL0498	906TFG, 4950TW	LL0899
Hardware	906TFG	4950TW	LL0533, LL0582 LL0811
Pressure Regulators	4950TW-1	4950TW-2	
Pressure Switches	LL0092, LL1303 4950TW		
Pumps	LL0933, LL0972 LL1054, 4950TW	LL0715	LL0582
Reservoirs	LL0119, LL0970	LL0600, LL1440	
Seals	LL0102, LL0188 LL1162, 906TFG 4950TW	LL0372	
Tubing	LL0016, LL0119 LL0359, LL0383 LL0764, LL0831 LL0844, LL1528 906TFG	4950TW	LL0811, LL0850
Valves	LL0044, LL0413 LL1440	LL0133, LL0622	LL0118, LL0582

Accumulators

Source	Problem	Corrective Action
LL0731	aircraft canopies often have to be opened manually because the accumulator is depleted	a manual servicing/ opening mechanism should be incorporated in the design of those canopy systems which incorporate an accumulator to open the canopy
LL0933	the nearly continuous motion in active accumu- lators cause early seal wearout; additionally, they are susceptible to allowing air to enter the hydraulic system	multiple and high speed hydraulic pumps can virtually eliminate acitve accumulators in hydraulic systems
4950TW	though a low failure item, accumulators on C-130s are difficult to access as they are located behind the hydraulic reservoir and several hydraulic lines	as much as possible, main system components should be provided easy accessability regard- less of the reliability of the component

Actuators

Source	Problem	Corrective Action
LL0092	lack of limit sensors at the extremes of travel on flight control surfaces can cause damage to aircraft components	travel limit sensor switches should be required in secondary, as well as primary, actuator systems for flight control surfaces
LL0613	approximately 16-20 man-hours are required to remove the upper attachment bolt of a system's speed brake actuator as both ejection seats and the actuator cover must be removed first	direct access to actuator attach points should be provided to eliminate the need for removal of other components for accessability
LL0812	high maintenance costs can result from integrating two or more systems and thereby increasing the system complexity as is the case on one aircraft which has an integrated slat and flap system	maintenance requirements must be considered to avoid the integration of complex systems which drive high maintenance costs
LL0965	a cargo aircraft did not have mechanical stops installed on the pitch trim actuator jack screw thereby allowing runaway longitudinal trim when the actuator limit switch failed	specifications should require mechanical stops on pitch trim actuators to provide maximum protection against runaway trim
LL1180	use of flight control actuators incorporating an extremely elongated configuration and having a high hydraulic boost ratio can result in less than optimum flight control	aircraft designers should avoid use of elongated actuators having an extremely high boost ratio without extensive analysis and component system testing
LL1599	control/actuator rods equipped with a "slotted", adjustable eye bolt allow water to enter the cavity of the rod through the keyway and cause corrosion	hollow control/actuator rods with the eye bolt should be designed with neither a keyway slot in the threads nor a tabbed lock washer

Filters

Source	Problem	Corrective Action
LL1080	excessive maintenance manhours are required to remove filters from hydraulic systems	specifications for hydraulic system design should consider: 1) a minimum number of filters in each hydraulic system and location behind quick-access doors, 2) use of high-capacity filters of the throwaway type requiring simple or no tools to remove or install, 3) use of identical pressure and return filters (interchangeable), and 4) use of pressure indicators for each filter and locate the filter so that the indicators are visible for inspection
LL1432	contamination level limits of hydraulic systems will be exceeded if the systems do not accept the correct size filters; this situation leads to excessive flushing of the hydraulic system	future designs should make certain that a hydraulic system can accommodate the filters necessary to maintain the system at the required contamination level
906TFG	on F-4s, three of the twenty filters can only be accessed by having the aircraft jacked as stress panels have to be removed	the location of filters should be provided easy access as they are checked often either during routine maintenance or for troubleshooting purposes
4950TW	filters are routinely and frequently checked for contamination, so this maintenance procedure should be streamlined as much as possible	consider designing a clear bowl to house the filter for visual checks instead of requiring removal of the filter element

Fittings

Source	Problem	Corrective Action
LL0395	cross-connecting hydraulic lines to a component can happen when identical fittings are used	hydraulic line fittings should be designed in a way that will make cross-connection difficult or impossible
LL0581	failure to locate hydraulic fittings with adequate clearance or where they are easily accessible without removal of equipment will result in excessive maintenance time	design specifications must require that fittings are easily accessible and installed with adequate work clearance
LL0582	removal and replacement of many hydraulic system components is very difficult and time-consuming	system specifications should require that replaceable components can be removed without removing other equipment, hydraulic lines, etc.; the use of flexible hydraulic lines and quick disconnect hydraulic fittings should be considered
LL0858	the sleeve type of Wiggins fittings in the hydraulic return lines are failing due to flange separation in the self aligning part of the tube to fitting interface	standard AN fittings with appropriate size wall thickness, straight swivel couplings, or rigid Wiggins fittings with flexible line segments should be used in hydraulic return lines
LL0881	hydraulic manifolds without enough clearance between the manifold fittings will hinder removal and replacement of the innermost hose fittings (see LL0581)	a hydraulic fitting clearance requirement for ease of maintenance should be incorporated as a hydraulic system requirement

LL1408	hydraulic components which have identical fittings for both the input and output could lead to the component being installed in the reverse direction	components shoud be designed to prevent inadvertent reverse installation
906TFG	aluminum fittings, though lighter than steel fittings, are easier to damage	designers should consider the trade-off between weight and durability when choosing the material for components

Fuses

Source	Problem	Corrective Action
LL0073	placing two or more hydraulic components through a common fuse can cause unnecessary failure of the operable unit when the other unit fails	each component should have a separate protection device
LL0498	a hydraulic line carries flammable liquid and may represent a fire hazard if it is not protected by a properly located fuse	hydraulic system design should require the use of fuses on both primary and emergency hydraulic lines; these devices should be situated to provide maximum protection against line or component rupture
LL0899	poor accessability to fuses drive up the removal and replacement time of the fuse	fuses should be located in a convenient location to assure simple and easy replacement
906TFG	though fuses have decals on them indicating installation direction, they can still be installed backwards	consider designing the fuse so that it is hard mounted with a clamp in one position
4950TW	though fuses have decals on them indicating installation direction, they can still be installed backwaards	design each fuse so it is physically different or possibly color code the fuses and the attachment points

Hardware

Source	Problem	Corrective Action
LL0533	hydraulic components which are fastened to the aircraft structure with semi-permanent fasteners are not easily removed	components which require frequent removal should be attached to the primary structure with easily removable hardware
LL0582	failure to design for and verify easy access to reparable and frequently replaced components increases repair time	system specifications should require that components can be removed without removing other equipment, hydraulic lines, etc.
LL0811	when components are not provided adequate accessability for maintenance, many manhours are expended in trying to reach and replace the failed items	ensure that components are provided adequate access
906TFG	hardware made of soft metals tend to round at the edges if they are removed often	use stainless steel hardware if the hardware will be removed often
4950TW	safety wiring components consumes a great deal of manhours	use self-locking nuts, or other techniques, when possible, to avoid safety wire

Pressure Regulators

Source	Problem	Corrective Action
4950TW-1	some pressure regulators are designed so they can be installed backward	design the pressure regulator so that it can only be mounted in one position
4950TW-2	the proliferation of parts can cause a great deal of time to be wasted if the wrong part is accidentally installed	parts should be standardized as much as possible and then should be physically different as well as being color-coded

Pressure Switches

Source	Problem	Corrective Action
LL0092	lack of limit sensors at the extremes of travel on flight control surfaces can cause damage to aircraft components	system specifications should require travel limit sensor switches in secondary as well as primary actuator systems for flight control surfaces
LL1303	use of a low pressure warning system that has an indicator light that only senses a low needle position on the pressure gage can result in erroneous warnings if the gage system fails	ensure that warning systems which monitor critical systems are separate from the primary indicating system
4950TW	there are induced failures to the electrical portion of pressure switches due to vibration in flight	a softer mount for the switch should dampen the flight vibration and thereby minimize the induced failures

Pumps

Source	Problem	Corrective Action
LL0582	removal and replacement of many hydraulic system components is very difficult and time-consuming	system specifications should require that replaceable components can be removed without removing other equipment, hydraulic lines, etc.; the use of flexible hydraulic lines and quick disconnect hydraulic fittings should be considered
LL0715	components that are required to operate in unison with minor deviations in output pressure should be designed with the capability for field level calibration	systems should not depend on components which require precise adjustment prior to installation
LL0933	the nearly continuous motion in active accumulators cause early seal wearout; additionally, they are susceptible to allowing air to enter the hydraulic system	multiple and high speed hydraulic pumps can virtually eliminate active accumulators in hydraulic systems
LL0972	conventional spline couplings used with such engine driven accessories as hydraulic pumps have demonstrated high wear rates	non-metallic adapters should be evaluated for all splined engine drive accessories
LL1054	when redundant accessories are driven from one common drive component, the possibility of total system loss lies in the strength of that one drive component	redundant drive sources should be required
4950TW	there are induced failures to pumps due to vibration in flight	a softer mount for the pump should dampen the flight vibration and thereby minimize the induced failures

Reservoirs

Source	Problem	Corrective Action
LL0119	the use of engine bleed air to pressurize hydraulic reservoirs may damage the reservoir, the tubing and the flex lines should the pressure regulator fail	engine bleed air should not be a source of reservoir pressurization
LL0600	if each reservoir is not equipped with its own quantity indicating gage, then excessive maintenance manhours will be used servicing units which do not require servicing	each reservoir should have a separate quantity indicator, located at the servicing point, and in addition to the indicator in the cockpit
LL0970	aircraft incorporating non-separated type hydraulic reservoirs may experience hydraulic failure if moisture removing elements within the bleed air components fail to remove all contaminants	the use of separated type reservoirs should be required whenever possible
LL1440	the location of the hydraulic systems bleed valves and reservoir gages may make it very difficult for one person to perform hydraulic system servicing and bleeding operations	consideration should be given to locating the reservoir gages and bleed valves close to the servicing area

Seals

Source	Problem	Corrective Action
LL0102	all components exposed to the environment, i.e., exposed to water in wheel wells, can be degraded should moisture enter the components	all components must be adequately sealed to prevent intrusion of the environment
LL0188	hydraulic problems can be experienced from o-ring twisting and rolling	t-seals with anti-extrusion devices provide good performance when o-ring twisting and rolling is experienced or predicted
LL0372	many pressure seals require removal of the components running through the pressure hull if the seal must be replaced	pressure seals should be designed to permit removal and replacement without component removal
LL1162	some seals do not effectively exclude contaminants or retain fluids when used in areas subjected to harsh environments (see LL0102)	seals that will be exposed to harsh environments should be environmentally tested per MIL-STD-810C
906TFG	standard o-rings tend to roll and come out of their grooves (see LL0188)	consider using GT (half-moon) seals instead of o-rings
4950TW	gaskets (stationary seals) wear out quicker than moveable seals because they aren't completely lubricated and therefore they crust from drying out	the reliability and maintainability trade-offs of using different types of seals must be explored when designing components

Tubing

Source	Problem	Corrective Action
LL0016	unsupported fluid system lines are subject to stress and vibration effects which result in failure	the reliability of rigid fluid system lines, as influenced by its installation, should be ascertained during design
LL0119	the use of engine bleed air to pressurize hydraulic reservoirs may damage the reservoir, the tubing and the flex lines should the pressure regulator fail	engine bleed air should not be a source of reservoir pressurization
LL0359	when thin-walled hydraulic tubing is used, flattening and ovality can result in the bend areas of the tubing	the tradeoff between the use of thin-walled tubing to save weight and the use of thicker-walled tubing to prevent ovality should be closely evaluated
LL0383	flight control systems powered by hydraulics can fail should an in-flight fire occur which destroys the hydraulic lines	thorough fire hardening of redundant lines for emergency hydraulic power for critical critical hydraulic systems such as flight controls can significantly increase the survivability from in-flight fires or explosions
LL0764	tubing and hoses have failed in various weapon systems when exposed to moving parts	tubing and hoses must be provided adequate clearance or protection from possible contact with moving parts
LL0811	when components are not provided adequate accessability for maintenance, many manhours are expended trying to reach and replace the failed items	ensure that components are provided adequate access

LL0831	routing redundant flight control tubing, wiring, and cables together could render the flight control inoperative if hit by enemy fire or otherwise damaged	redundant flight control systems should not be routed together
LL0844	aircraft fires can occur when electrical wiring and tubing carrying hydraulic fluid, fuels, or gases are routed in close proximity or clamped together	wiring and tubing carrying different volatile material should be routed in such a way that electrical arcing cannot cause a fire
LL0850	the removal of large cargo compartment floor panels is required to gain access to the nose landing gear hydraulic lines under the floor of one aircraft	access to underfloor hydraulic lines should be accomplished by one of the following: provide properly stressed access panels in the cargo floor which would eliminate the need to remove large floor panels, or route the hydraulic lines through more accessible areas
LL1528	locating hydraulic lines in leading edges without any protective bulkheads can result in loss or degradation of flight controls and possibly inflight fire/loss of aircraft	special attention should be paid to the impact damage susceptability of routing paths used for flight critical plumbing; consider routing the plumbing in wing leading edges behind control surfaces or wing structural supports
906FFG	rubber hoses are less reliable and require more maintenance than teflon hoses	teflon hoses don't weather, they last longer, they are ea[illegible] to manufacture, an[illegible] they don't requir[illegible] time change as th[illegible] rubber hoses [illegible]

AD-A188 097 ELECTRICAL/PNEUDRAULIC DESIGN CONSIDERATIONS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYSTEMS AND LOGISTICS R L FENNELL SEP 87 2/2

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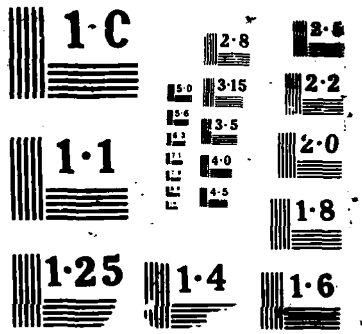
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4950TW	tubing is inflexible and can therefore present problems during maintenance	consider replacing the tubing with steel braided, hi-pressure teflon hoses in high flex areas

Valves

Source	Problem	Corrective Action
LL0044	valves with lead seals leak after several opening and closing operations requiring replacement of the complete valve assembly	reparable valves which have a long service life and seal material which can withstand many operations before replacement should be used
LL0118	servicing access problems and time consuming maintenance workaround procedures can be caused when an aircraft is under maximum load characteristics	maintainability requirements should include minimum and maximum characteristics of an aircraft
LL0133	look-alike servicing valves may lead to inadvertent connection to the wrong pressure	specifications should require proper identification of servicing valves either by color code or physical shape to prevent erroneous applications of pressures
LL0413	incorporating several bleed valves in a hydraulic system which has a self bleeding design can create added maintenance work	hydraulic systems that employ a self-bleeding capability through system operation should be designed with a minimum number of bleed valves
LL0582	failure to design for reparable and frequently replaced components increases repair time	reparable/replaceable components should be able to be removed without removing other equipment
LL0622	lack of shutoff valves to isolate portions of a system can result in increased maintenance requirements and decreased aircraft readiness	manual shutoff valves should be considered as a design feature in hydraulic systems

LL1440	the location of the hydraulic systems bleed valves and reservoir gages may make it very difficult for one person to perform hydraulic system servicing and bleeding operations	consideration should be given to locating the reservoir gages and bleed valves close to the servicing area

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VITA

Captain Ricky L. Fennell was born on 4 December 1957 in Butler, PA. He graduated from Karns City Area High School, PA in 1975. In May 1979 he obtained a Bachelor of Science degree in Business Administration from Slippery Rock State College. Upon graduation, he received a commission in the USAF through the ROTC program. His first assignment was as a program manager on the Low Altitude Navigation and Targeting Infrared System for Night (LANTIRN) Head-Up Display program at Wright-Patterson AFB OH from June 1979 to July 1983. During this time he also obtained a Master of Arts degree in Personnel Management from Central Michigan University.

After six months at the Aircraft Maintenance Officer Course at Chanute AFB IL, Captain Fennell was assigned to the 4950th Test Wing at Wright-Patterson AFB as an aircraft maintenance officer. He spent time in both the Organizational and Field Maintenance Squadrons as their maintenance supervisor. In 1985 he won the Air Force Systems Command Outstanding Aircraft Maintenance Company Grade Manager of the Year award. In June 1986, Captain Fennell started studies on his second Masters' degree when he entered the Air Force Institute of Technology, School of Systems and Logistics.

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Block 19. Abstract

The purpose of this research was to examine ways that the reliability and maintainability (R&M) of aircraft electrical and pneudraulic components and systems could be improved. To accomplish this task two R&M databanks for the components under review were researched. Added to this information were the opinions of electrical and pneudraulic aircraft maintenance technicians from two organizations assigned to Wright-Patterson AFB OH.

The results of the document reviews and interviews were a list of specific problem areas and suggested corrective actions for each. These problem areas were then categorized into general recommendations to improve the reliability, maintainability, and subset of maintainability, accessability of the electrical and pneudraulic systems.

This thesis should be looked at a management document providing general guidelines for designing aircraft electrical and pneudraulic systems. As these systems are functionally similar to other aircraft systems, such as fuel, propulsion, and environmental systems, the recommendations put forth may also apply to thse systems.

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